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Energy-Efficient Lighting on U.S. Army Installations

Lighting Retrofit Survey

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Foreword

This research was performed for the Director of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project 4A262784AT45, "Energy and Energy Conservation"; Work Unit XH7, "Lighting/Electrical Technology." The technical monitor was Thomas Luu, CESWD-ETEC.

The research was performed by the Energy Branch (E), of the Facilities Division (CF), of the U.S. Army Construction Engineering Research Laboratory (CERL). The USACERL principal investigator was Elisabeth Jenicek. Christine Zimmer and Aide Uzgiris were Research Assistants associated with the University of Illinois, Urbana-Champaign (UIUC). Larry Windingland is Chief, CEERD-CF-E; and L. Michael Golish is Chief, CEERD-CF. The CERL technical editor was William J. Wolfe, Information Technology Laboratory. The associated Technical Director was Gary W. Schanche, CEERD-CV-T. The Acting Director of CERL is Dr. Alan W. Moore.

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1 Introduction

Background

Electrical lighting is a major consumer of energy in Army facilities. It accounts for approximately 25 percent of facilities' energy and contributes to daytime energy peaks. Lighting also accounts for 20 percent of the building air-conditioning load.

Lighting retrofits are often the first energy projects to be completed on post because they require a relatively low investment and yield a quick simple payback. Over $40 million in Energy Conservation Investment Program (ECIP), Federal Energy Management Program (FEMP), and service operation and maintenance (O&M) funding was spent on lighting retrofits between fiscal year 1993 (FY93) and FY98. Major lighting upgrades are currently being done under Energy Saving Performance Contracts (ESPCs).

At the same time, major advances have been made in the energy-efficiency of commercial off-the-shelf (COTS) lighting technology. Lighting quality has improved significantly due to newer materials. Strong demand for new products has increased their availability, and consequently reduced their cost.

Despite these advances in the availability of advanced lighting technologies, Army installations do not always realize successful lighting retrofits. This study was undertaken to review and present the tools, technical support, and processes available to installation staff involved in the lighting retrofit process.

Objectives

The objectives of this study were to determine penetration rates of energy-efficient lighting technologies on Army installations, to identify obstacles to implementing cost effective lighting projects, and to provide tools and techniques for evaluating lighting projects.

Approach

A written survey was administered to 107 continental United States (CONUS) and 47 outside continental United States (OCONUS) energy managers between July and September 1997. The survey requested demographic information, opinions on new lighting technologies, experience with lighting retrofit projects, criteria for planning lighting retrofit projects, penetration rates of new lighting technologies on post, technologies used in FEMP or ECIP funded lighting retrofit projects, and barriers to obtaining high-technology lighting systems. Ample opportunity was provided for narrative comments. Results of this survey were analyzed using SPSS software.

This survey was a follow-on to a short "Lighting Needs Survey" administered to attendees at the 1996 Department of Defense (DOD) Energy Manager's Conference in Milwaukee. The results of the earlier survey are also reported here.

Mode of Technology Transfer

It is anticipated that the information from this study will be included in educational venues for Army Energy Managers and engineering design personnel, including the Army Energy Managers Training Course and the DOD Worldwide Energy Conference.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

SI conversion factors		
1 in.	=	2.54 cm
1 ft	=	0.305 m
1 yd	=	0.9144 m
1 gal	=	3.78 L
1 lb	=	0.453 kg
1 kip	=	453 kg
1 psi	=	6.89 kPa
°F	=	(°C x 1.8) + 32
1 footcandle (fc)	=	10.76 lumen / m^2
1 lux	=	0.0929 fc

2 Lighting Project Issues

Introduction

Lighting consumes approximately 25 percent of a typical Army facility's energy. Since lighting uses high-cost electrical energy, it provides an attractive target for energy trimming efforts. Illumination systems are also cheaper to retrofit and less complex than many other building systems such as central heating or cooling plants or building automated control systems. New lighting technologies offer opportunities to decrease energy use and improve the quality of lighting in a single step. Low risk, proven technologies can reduce lighting energy use by 50 to 75 percent.

Designing lighting projects has been greatly simplified in recent years. The tremendous advances in energy-efficient lighting technology over the past decade have provided a pool of cost-competitive products. Analysis and design computer programs have eased the job of selection, design, analysis, and simulation.

Given these technological advances and cost advantages, one might think that Army facilities should have some of the best lighting systems available—energy-efficient technologies with state-of-the-art control capabilities that support visual performance and create comfortable places to work. However, this is not always the case.

Improvements in Lighting Technology

The rapid development of advanced energy-efficient lighting products over the past decade has provided many alternatives for lighting retrofits. The tri-phosphor coated T-8 lamp not only can reduce energy consumption by 20 percent, but can also improve the quality of light available. Tri-phosphor coated T-8 lamps provide more lumens per watt and higher color rendering index (CRI) ratings than the single phosphor coatings on standard T-12 lamps. A larger variety of styles (triple twin-tube), lengths (up to 24 in.), and wattages (7 to 55 watts) for compact fluorescent lamps (CFL) are currently on the market. CFLs are now capable of shallower luminaire design and improved optical control to benefit indirect lighting. The development of dimming ballasts for CFLs has widened

their extent of use and increased opportunity for energy-savings. Traditional U-shaped lamps are frequently being replaced by CFLs due to their higher lumen output.

Fluorescent lighting systems that use high-frequency electronic ballasts (as opposed to systems that use electromagnetic ballasts) increase their energy efficiency by 6 to 29 percent. Energy efficiency may be improved by about 59 percent when systems are upgraded to include T-8 lamps. The high frequency of the electronic ballast (between 20 and 60 kilohertz [kHz]) allows lamps to operate approximately 10 to 15 percent more efficiently. This produces more illumination while reducing the amount of noise or ballast hum. The reliability and cost-effectiveness of electronic ballasts has vastly increased. Electronic ballasts have been improved to provide 2-, 3-, or 4-lamp capabilities. Manufacturers have improved production techniques to eliminate early failure of electronic ballasts.

Automated controls, such as daylight and occupancy sensors, provide energy savings by regulating lighting operation. The sensors may be wall- or ceiling-mounted. Generally, a building's power-distribution system or a separate low-voltage wiring system receives control system signals to turn lights on and off. Ambient daylight is the basis for the electric lighting control for daylight sensor systems. Reduced maintenance costs, longer lamp life, and elimination of initial overlighting generated by designs for maintained light levels are some of the benefits of implementing daylight sensors. The most popular occupancy sensors allow lighting control in specific areas with the use of ultrasonic (US) units that activate when any motion is detected, or passive infrared (PIR) units that activate when heat motion is detected. Use of occupancy sensors result in typical burn time savings of 25 percent for single occupant offices, 75 percent for restrooms, and 40 percent for conference rooms.

New reflector/louver systems for parabolic troffers have been designed to reduce visual display terminal (VDT) screen glare. Screen glare is reduced by the optical system, which prevents the emission of light at high angles. Applying a low-iridescent finish for luminaire louvers and reflectors can minimize the rainbow effect sometimes produced by triphosphor lamps. In comparison to the white paint that lines most existing luminaires, reflectors now have the ability to significantly decrease the internal losses of luminaires and minimize or maximize their light distribution due to their higher reflectivity and wider range of directional control.

Restrictions on Manufacturing

Legislation for lighting design has been enacted within the past 10 years at Federal, State and local levels. The 1988 Federal Ballast Energy Law prohibits the manufacturing of "standard" magnetic ballasts and mandates the use of high-efficiency, energy-saving, electromagnetic or electronic ballasts. Many states have enacted building power regulations based on the 1989 American Society of Heating, Refrigerating and Air Conditioning Engineers/Illuminating Engineering Society of North America (ASHRAE/IESNA) 90.1 Standard. The U.S. Energy Policy Act of 1992 (EPACT) prevents manufacturers from producing "traditional" lamps due to their low efficiency.

Funding of Energy Projects

Executive Order 13123 (3 June 1999) called for comprehensive facility audits to identify cost-effective energy technologies to attain a 30 percent energy reduction by 2005 and 35 percent energy reduction by 2010. This supercedes the previous goals requiring a 30 percent reduction from 1985 to 2005 required by Executive Order 12902, "Energy Efficiency & Water Conservation at Federal Facilities."

This earlier goal was cushioned with funding in the form of FEMP set-asides for the entire DOD. FEMP funding peaked at $75M in FY96. Though the fenced nature of FEMP funding disappeared in FY97, the Army continued to fund energy projects through its operations and maintenance (O&M) account. The present goal is to be accomplished using ESPCs since very little in-house funding is typically available for lighting projects. Figure 1 shows historical funding for ECIP, FEMP, and Army O&M.

Each of these financing programs operates on its own time line, with a different cast of characters, and a unique set of playing rules. As might be expected, installation energy managers have a difficult time identifying and capturing appropriate sources of funding for potential energy projects.

The types of projects completed using ECIP and FEMP funding vary widely ranging from energy control upgrades and central plant conversions to building weatherization and lighting system improvements.

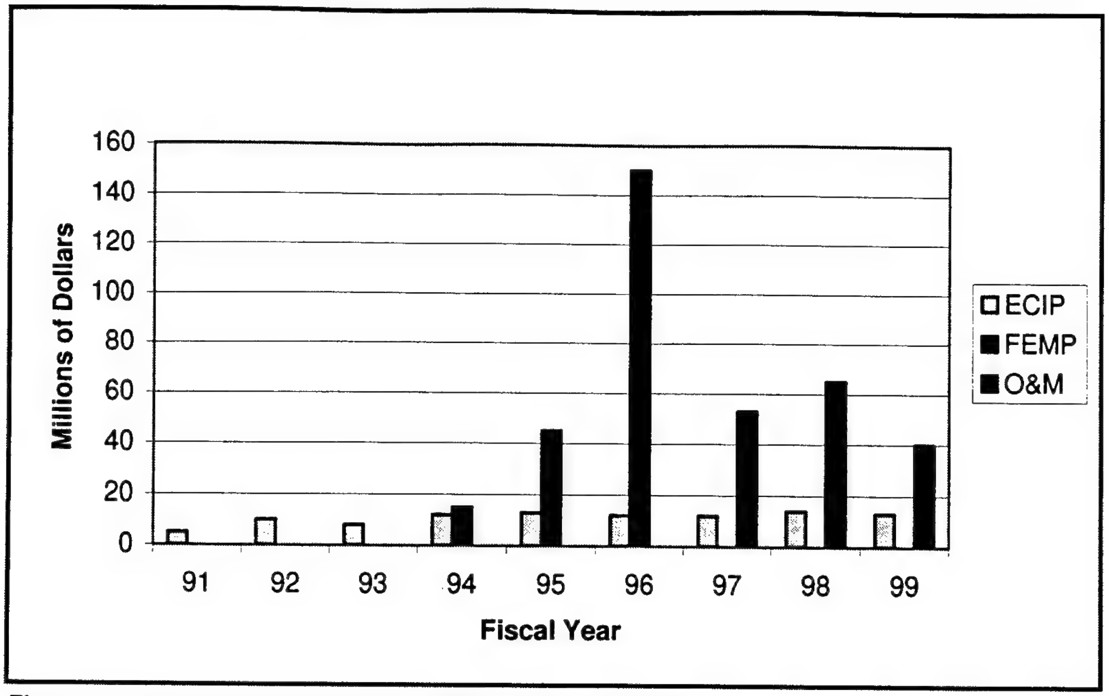

Figure 1. Historical funding for ECIP, FEMP, and Army O&M.

The centralized funding of energy efficient projects has been sporadic and unpredictable. From the peak of the ECIP in the 80s, hundreds of millions of dollars were spent on qualifying projects. The Army supported the centralized development of energy projects through the Energy Engineering Analysis Program (EEAP). Products within EEAP included an analysis of an installation's energy consumption along with recommended energy projects, complete with DD1391s (*Military Construction Project Data [LRA]* [December 1976]) and life cycle cost analyses (LCCA).

Funding dwindled to less than $10M a year by the time the Energy Policy Act of 1992 (EPACT) was signed by President Bush. Hundreds of millions of energy set-asides have been replaced by legislative authority to enter into alternative financing arrangements with the private sector.

Alternative Financing is the term used to describe projects not using capital appropriations. Simply put, "Alternative Financing" refers to projects executed on Army installations that are financed by the private sector. Alternative financing has been an option for years but has become more important as traditional energy project funding sources have been reduced or eliminated. The first is utility demand side management (DSM) incentives. Though widespread in the early 1990s, these programs have vanished in a utility environment dominated by the dawn of deregulation.

DSM as a resource has been replaced in part with Energy Saving Performance Contracting (ESPC). ESPC is a process by which contractors audit Federal facilities, propose energy saving retrofits, and privately finance, install, operate, and maintain retrofits. Contractors are paid by receiving a portion of the cost savings realized through reduced energy consumption due to the retrofit. Remaining savings return to taxpayers and the agency. The authority to use ESPCs is derived from section 155 of the Energy Policy Act (EPACT). The President released the memorandum entitled Federal Use of Energy Savings Performance Contracting on 25 July 1998. Government-wide regulatory guidance on ESPC is contained at 10 CFR 436. This memo was intended to encourage increased use of ESPC and improve Federal energy management. Executive Order 13123 further encourages use of ESPC as a means of alternative financing.

The use of ESPCs has been simplified by the availability of existing contracting vehicles through the Department of Energy and the Huntsville Division of the Army Corps of Engineers. The Defense Energy Support Center is also developing ESPC contracts. The Department of Energy has awarded Super ESPC contracts covering its six geographic regions and three Technology Specific ESPC contracts. These contracts are available to all government agencies as a vehicle for using ESPCs. The Federal Energy Management Program (FEMP) developed model procurement documents, the Measurement and Verification Guideline for Federal Energy Projects, a how-to manual for ESPCs, a home page on the Internet, and educational videos for management, legal, and contracting personnel.

In the Corps of Engineers, Huntsville Engineering and Support Center has been designated as the Technical Center of Expertise for ESPC projects within the Army. To date, Hunstville has developed and awarded 27 performance contracts for various U.S. installations.

The Energy Policy Act of 1992 (EPACT) authorizes and encourages Federal agencies to participate in utility incentive programs entitled Utility Energy Service Contracts. These programs range from rebates on equipment, to delivery of complete turnkey projects. Services provided for a project can range anywhere from auditing to installation and commissioning, and may include financing the entire project. Utilities may cover the capital costs of the project in consideration of the energy savings the retrofits will produce. In this arrangement, the net cost to the Federal agency remains minimal, and the agency saves time and resources by using the "one-stop shopping" provided by the utility. Utilities are one source for financing Federal projects. FEMP provides guidelines to help Federal facility personnel select the most appropriate utility contracting vehicle and put a contract in place.

Analysis of Retrofit Options

Many software tools became available in the early 1990s, spurred on by Federal policy that mandated rapid decrease in energy use and the infusion of energy conservation with tens of millions of dollars annually to assist in this achievement. The Department of Energy (DOE) web site provides access to many of those lighting tools: http://www.eren.doe.gov/

Lighting Analysis Software

Renewables and Energy Efficiency Planning (REEP).

The REEP system was developed at the U.S. Army Construction Engineering Research Laboratory (CERL) to provide users with a flexible analysis tool for evaluating Energy and Water Conservation Opportunities (ECOs/WCOs) at Department of Defense (DOD) installations. The user is permitted to carry out "what if" types of analyses specific to lighting by modifying the default data according to their needs. Lighting technologies are evaluated for their energy savings potential, financial viability, and pollution abatement potential. A quick, broad overview of resource savings potential at DOD facilities is produced in a detailed or summarized report format by the program. The Army REEP program is updated annually to reflect changes in real property data, fuel costs, discount factors, and penetration rates of ECOs.

Energy Manager Project Assistant (PA)

The Energy Manager Project Assistant (PA) software program created by CERL provides a standard methodology for energy project calculations. This program allows energy managers to choose among various energy and water conservation opportunities and to accurately carry out engineering calculations and prepare DD1391s and supporting economic analyses using standard algorithms. The prototype PA software contained three lighting energy conservation opportunities (ECOs): retrofit/replacement of 4-ft linear fluorescents with T-8 lamps and electronic ballasts, retrofit/replacement of incandescent with compact fluorescent lamps (CFL), and retrofit/replacement of exit signs with light-emitting diode (LED) technology. An updated version of PA allows for 13 additional energy and water conservation opportunities. These are comprised of resource efficient washing machines, faucet aerators, shower heads, energy efficient motors, LED traffic signals, flush valves, high watt incandescent, refrigeration LPAs, high efficiency gas boilers, high efficiency chillers, adjustable speed drives, direct digital controls, and T-5 fluorescent lighting. The PA software also calculates an ESPC

economic analysis in addition to the ECIP analysis to help evaluate contractors' proposals.

Facility Energy Decision System (FEDS)

The Facility Energy Decision System (FEDS), developed by Pacific Northwest National Laboratories (PNNL) was modified for the DOD to provide a resource-planning tool for determining minimum life-cycle cost (LCC) configurations of an installation's energy generation and consumption infrastructure. FEDS has the capability to analyze the economic potential of energy efficient technologies at DOD facilities. It models (in detail) all interactive effects between energy systems within and between buildings. The model chooses technologies that will maintain an exceptional level of service, such as illumination, at a minimum LCC. This provides the user with an illustration of the effects of the retrofit in different aspects of the building. Minimum or detailed information may be entered into the program, producing a less accurate report or an optimal retrofit technology configuration. Use of the FEDS software will provide a more systematic and optimal energy reduction plan for DOD installations.

Federal Relighting Initiative

The Federal Relighting Initiative is intended to maintain/improve the existing quality of light while reducing power consumption dramatically. The program provides lighting evaluation tools and retrofit information to facility managers. Significant reductions in the amount of energy used for lighting and lighting maintenance costs, as well as an improved work environment may result from merely relighting a building. A reduction of 1.5 watts per square foot for lighting power densities in new buildings and major renovations can be achieved by installing modern, efficient luminaires, replacing ballasts and lamps with modern components, implementing task/ambient lighting, and installing lighting controls. Lower lighting power densities resulting from sensitive design and refurbishment have the ability to surpass ASHRAE 90.1 guidelines.

LightPAD (LPAD)

The Electric Power Research Institute (EPRI) developed the LightPAD (LPAD) as a flexible, auditing tool that is capable of on-site analysis of single buildings and all data input. This allows the lighting auditors to greatly condense their work. Evaluations can be performed for new construction as well as retrofits. LPAD can quickly estimate a building's lighting energy use and/or existing lighting levels, and allows modifications of variables to define and compare alternative lighting systems.

Federal Lighting Energy Expert (FLEX)

The Federal Lighting Energy Expert (FLEX) uses a lighting characterization tool that surveys applications ranging from a single room to multi-building complexes. Typically, FLEX is used for single buildings. Users are capable of analyzing relighting projects due to its "expert" system. FLEX ensures that the user supplies complete information with the help of a screening expert and optionally generates and analyzes relighting cases. The "Quick Inputs" feature automates most of the lighting characterization process. Lighting equipment databases are used to simplify the survey process, allowing users to choose the appropriate fixture, lamp, or other item from provided lists. The survey data is then organized according to a relational database structure that allows direct entry of lighting equipment price and performance information. FLEX/Quick Inputs defaults may be directly edited when new input files are constructed. Results can be examined for an individual room, a lighting system, or an entire building. FLEX performs complete Illuminating Engineering Society of North America (IESNA) zonal cavity lighting calculations for each defined room and provides special reports that allow users to compare projects or examine lighting levels and targets in buildings. A building-level report compares calculations to light-meter readings and IESNA recommendations, including partition factors and light-loss calculations. FLEX contains the complete set of required LCC economics for Federal relighting projects, including: effects of user-defined local equipment prices; Energy Information Administration fuel escalation rates; heating, ventilation, and air-conditioning (HVAC) system effects; and a host of other adjustable factors. FLEX also provides a library (Photo Gallery) of images and case studies that cover different subjects in lighting quality.

Federal Renewable Energy Screening Assistant (FRESA)

The Federal Renewable Energy Screening Assistant (FRESA) Version 2.1 provides quick, accurate evaluation of renewable energy opportunities and energy systems options that could be included in a facility's energy program. FRESA is an addition to the energy audits for all Federal buildings. It records renewable energy opportunities by simplifying the evaluation and ranking procedure. Building and facility information is processed to demonstrate possibilities for renewable energy applications in Federal facilities and buildings. The main objective of the feasibility study efforts is to concentrate on applications that are anticipated to be the most cost effective. Database weather and technology/energy cost parameters are generated as FRESA's uniform assumptions. The reports generated by FRESA are compatible with the DOE/FEMP SAVEnergy Audit format.

Lighting System Screening Tool (LSST)

The Lighting System Screening Tool (LSST) screens for the greatest LCC reduction in lighting systems according to building type. LSST was developed to enable Federal facilities to comply with required LCC for energy equipment investments, consistent with the requirements of 10 CFR 436 in support of the Federal Relighting Initiative. The LSST prioritizes a list of buildings according to those that provide the maximum potential for LCC reduction in lighting systems by performing two levels of analysis. General information about the buildings to be analyzed, such as building type, size, operating hours, etc., is required for the first analysis level. Then, based on the building type, LSST acts on assumptions about the baseline lighting types and operating characteristics for each building. The second analysis level requires additional data about the existing technologies within each building, their densities in up to five building sections, and their hours of operation. This information is gathered during a walk-through audit of the building's lighting.

Lighting Technology Screening Matrix (LTSM)

The Lighting Technology Screening Matrix (LTSM) was developed to assist Federal facilities in adhering to LCC mandates brought on by the Federal Relighting Initiative. The LTSM determines the LCC of an existing fixture and numerous potential energy-efficient replacements (one-for-one replacements and lumen-equivalent). The existing lighting system is assumed to have reached half of its useful life for the LTSM calculations of the net savings of immediately retrofitting the existing system with alternative lighting options. It estimates annual energy savings, energy cost savings, and annualized total cost, including annualized capital costs, maintenance costs, and energy costs for each retrofit alternative. In addition, it is possible to use the LTSM to evaluate retrofits for various common configurations of fluorescent, incandescent, high-intensity discharge (HID), and exit lighting systems for any level of operation, electricity price, discount rate, and utility rebate program.

QuikPlan

The QuikPlan software tool provides Energy Star Buildings members with the assistance to plan, manage, track, and report building upgrades. This is accomplished through the analysis of the upgrade benefits that were discovered among several facilities. Similar buildings located in the same climate zone are compared to the analyzed buildings for energy performance ratings. QuikPlan prompts the user to provide facility utility data and upgrade costs, then to choose actions for each facility. From the input, long-term financial and energy effects

are projected. In addition, the program produces reports to meet the requirements for the Energy Star Buildings reporting commitment. QuikPlan provides users with the information to select the optimum buildings for upgrades.

ProjectKalc

ProjectKalc is a software tool that provides an energy and economic analysis of lighting upgrades covering everything from relamping, to delamping, to controls and tandem wiring. The program includes equipment costs, labor time, and performance criteria inputs as well as user-modifiable databases of costs, labor time, and performance.

Lighting Design Software

Lumen Micro

Lumen Micro by Lighting Technologies, Inc. is a lighting design, analysis, and specification program that allows users to create lighting layout simulations for indoor and outdoor applications. Its computer-aided drafting (CAD) capabilities allow Lumen Micro to easily model spaces and produce accurate numerical and graphic results. Lumen Micro's photometric library of over 60 manufacturers including 25,000 products enables the user to search using various criteria supplied by manufacturers. Layouts are easily illustrated and manipulated due to a variety of three-dimensional views. Gray-scale renderings provide a photo-realistic visual of the user's design. Lumen Micro also contains an integrated link to Lightscape, which is capable of generating photo-realistic color renderings of Lumen Micro designs.

Lightscape

Lightscape, by Lighting Technologies Inc., produces full-color photo-realistic images of lighting design layouts. As a visualization tool, it is capable of rendering Lumen Micro designs. "Real-world" lighting is combined with radiosity and ray-tracing technologies in Lightscape to simulate actual physical characteristics of light and various textures that alter lighting effects. Lightscape employs IESNA specifications from manufacturers. This enables users to present an accurately analyzed and rendered model of a space or object with specific textures and lighting conditions.

Photopia

Photopia by Lighting Technologies, Inc. is a precise photometric analysis program. It produces complete performance evaluations for optical designs without imaging. Computer modeling allows the testing of numerous design variations without changing figure work. Photopia contains numerous output options, which provide the user with the ability to use various metrics to characterize luminaire performance. It provides extensive performance statistics. The analysis reports include the luminous intensity distribution, luminaire efficiency, coefficient of utilization (CU) values, and a zonal lumen summary. The outputs illustrate which materials provide the highest amount of light absorption and the required number of reflections for light to exit the luminaire. Photopia also allows the user to establish the amount of traced rays and the number of reflections that they undergo. Continuous simulations may be interrupted to begin a new simulation or to revise the existing design. The displays of luminous intensity include candela curves, contour plots, and shaded images. The user chooses the photometric angles to be reported on. Photopia allows illuminances to be determined for multiple, user-defined rectangular planes, and to be displayed as contour plots and shaded images. Photopia's library of over 75 lamp types provides users with the ability to build individualized lamp models. Luminaire designs built in CAD are capable of being imported into Photopia.

Simply Lighting (Series)

The Simply Lighting Series by Lighting Technologies, Inc. includes three separate lighting analysis tools that are application specific. The three tools individually carry out common necessary calculations for outdoor, indoor, and roadway applications (Simply Outdoor Lighting, Simply Indoor Lighting, and Simply Roadway Lighting). Every Simply Lighting program has a photometric library of over 60 manufacturers, including more than 25,000 products.

Simply Outdoor Lighting enables the user to complete a lighting layout and model for any exterior application. The program allows users to design with its own CAD system or import and export drawings from other CAD programs. Simply Outdoor Lighting adopts the user's specified design guidelines to produce the most ideal lighting layout. The user determines the spacing between calculation points as well as masking points that are to be neglected in the calculations. Then Simply Outdoor Lighting executes precise point-by-point calculations. Luminaire Iso-Templates provide a general guideline for arranging luminaire placement and spacing. Gray-scale shaded plots, scaled drawings, and illuminance contours are included in the reports generated by Simply Outdoor Lighting.

Simply Indoor Lighting applies the user's design guidelines, then optimizes the indoor lighting layout. The program takes into account a target illuminance level, then estimates the number of luminaires required. Simply Indoor Lighting produces ideal lighting layouts and fits these layouts to existing ceiling grids. It produces customizable calculation grids as well as completes point-by-point direct illuminance calculations for orthogonal rooms and illuminance level calculations for a designated amount of luminaires. Complete zonal cavity analyses and estimations for the interreflected illuminance component are carried out. Four different lighting layouts can be compared at the same time and a maximum of four different luminaire layouts in one room can be combined. Simply Indoor Lighting calculates the entire connected load for each system. Simple cost comparisons are also performed. Scaled drawings, shaded plots, and illuminance contours are included in the report generated by Simply Indoor Lighting.

Simply Roadway Lighting generates lighting layouts for roadways. It can also create custom multi-lane roadway arrangements. Point-by-point horizontal illuminance, roadway luminance, and veiling luminance ratios for straight roadway sections are calculated. A maximum of eight different design criteria can be calculated to meet illuminance, roadway luminance, and veiling luminance ratio targets. A maximum of four different roadway layouts can be compared at the same time. The illuminance level for a designated number of luminaires is calculated. Simple system cost comparisons are performed. Scaled drawings, shaded plots, and contour maps are included in the report generated by Simply Roadway Lighting.

Increased Assistance for Selecting/Replacing Lighting

An increasing number of organizations provide assistance for selecting and replacing lighting. The following sections provide a partial list.

Energy Service Companies (ESCOS)

Energy Service Companies are generally private companies that sometimes perform auditing free of charge. Once the auditing has been completed, the ESCOS are paid to perform the work.

Utilities Monitoring and Control Systems (UMCS) Assistance

Utilities Monitoring and Control Systems (UMCS) monitor and control HVAC systems, electrical systems, and other utility systems within Army installations. The UMCS reduce costs and conserve energy through various methods ranging from simple local controls such as time switches, to sophisticated systems, which

use computer programs that monitor and control energy use and equipment operation. Engineering support and technical advice for UMCS is provided by the Mechanical and Energy Division of the U.S. Army Corps of Engineers Installation Support Division (CEISC). This assistance includes: system evaluations that determine whether or not the installation's needs are met, optimal system selection, control and monitor point selection, system purchase specifications and proposals reviews, acceptance testing and inspection evaluation, existing hardware and systems design modification reviews, and control strategies reviews.

Defense Logistics Agency (DLA)

The Defense Logistics Agency (DLA) provides supply support, contract administration services and technical and logistics services. The DLA purchases supplies for and provides supplies to the military services while supporting their materiel acquisition. The DLA also supplies support for the disposal of materiel that is out-of-date, worn out, or no longer necessary. Its facilities range from supply centers, to in-plant residencies with defense contractors, to property reutilization offices. The DLA includes a selection of numerous items, a distribution system, specialized contract management services from pre-award to post-award, worldwide property disposal services, information on available excess Defense Department property, worldwide hazardous material disposal services and information on management of hazardous materials. In addition, it includes logistics information from the Federal Catalog System, including sources, item descriptions and prices, and technical logistics services, such as specialized product testing.

Energy Efficient Lighting Catalog

The Energy Efficient Lighting Catalog provided by the General & Industrial (G&I) Directorate of the Defense Supply Center Philadelphia (DSCP) supplies information about environmentally-friendly lighting products, which produce better quality light while lowering power consumption. This assists the user with the selection of energy efficient products. Energy efficient products in fluorescent, compact fluorescent, high intensity discharge, halogen, and specialty lighting categories allow DSCP to provide effective lighting solutions. The catalog includes a table of the requirements for the EPACT of 1992. In addition, the catalog supplies a list of products that will no longer be manufactured, the dates on which manufacturing ceased, and acceptable products that may be used in place of items that have gone out of production. The catalog is available on the DSCP Internet site at:

http://dscp103.dscp.dla.mil/gi/general/light1.htm

Energy Savings Performance Contracting (ESPC)

Energy Savings Performance Contracting (ESPC) was authorized by the Energy Policy Act of 1992 (EPACT). ESPC enables energy service companies to assume the capital costs of installing energy conservation equipment and renewable energy systems. A fixed amount of energy cost savings is ensured by these companies throughout the life of the contract with the agency. Their payment is then acquired directly from those cost savings while the remainder of the cost savings goes to the agencies. ESPC offers the following benefits: energy cost reduction, Federal energy efficiency improvement, assistance for meeting the Federal energy savings requirements of Executive Order 13123 and EPACT, elimination of maintenance and repair costs of aging or obsolete energy-consuming equipment, and the placement of O&M responsibilities on the contractor. ESPC helps Federal agencies to reduce operating costs by training maintenance employees, updating aging building systems, and improving the efficiency of operations.

Pacific Northwest National Laboratory (PNNL)

Pacific Northwest National Laboratory (PNNL), managed by Battelle Memorial Institute, is a DOE multi-program National laboratory. It uses its abilities to fulfill specific energy requirements. Environmental science and environmental technology comprise most of PNNL's work. The laboratory provides major contributions in science and technology as well as energy. PNNL has been appointed a principal laboratory in the environmental quality mission since its mission is in agreement with the DOE's Strategic Plan and Strategic Laboratory Mission Plan.

Battelle

Battelle offers its users innovations that improve energy products and services, provide product identification, and supply feasible solutions for environmental problems, while achieving a cost-effective regulatory compliance. It provides these services through energy product and system simulation and performance evaluation, and energy product development.

Energy Star Buildings

Energy Star Buildings and Green Lights partner member organizations and the U.S. Environmental Protection Agency (USEPA) as advocates for encouraging energy efficiency in buildings. Energy Star provides the tools that allow energy-efficiency efforts to be supported. The use of energy efficient lighting technologies has helped many companies significantly reduce their overall energy bills,

thereby encouraging widespread use of energy-efficient lighting. Program participants realize their primary goal of saving energy by becoming more energy efficient. In addition, they reduce energy costs while preventing pollution. Numerous technical publications that contain case studies demonstrating how others have benefited from the partnership are available. The Energy Star Buildings Manual provides partners with the required information to plan and execute a viable energy strategy. The Lighting Upgrade Manual provides extensive information on planning, financing, and executing projects and disposing of lighting waste, as well as communicating success. In addition, it enables users to learn about the latest technologies and strategies for upgrading building lighting systems. Additional information and resources are available on the Energy Star Buildings Internet site: http://www.epa.gov/greenlights.html/

E Source

E Source is an information service company providing organizations with unbiased, independent analysis of retail energy markets, services, and technologies. Members receive newsletters and have access to the "members only" section of the web site. Hundreds of publications are available for purchase.

E Source's clients include electric and gas utilities and other energy service providers, large corporate and institutional energy users, government agencies, energy service companies, manufacturers, consultants, research institutions, and other organizations in nearly two dozen countries worldwide. The E Source web site is located at http://www.esource.com/

Lighting Design Issues

Poorly designed lighting can impact severely on worker productivity. Fatigue, eyestrain, headaches, and backaches are associated with compensation for bad lighting. Traditional methods of lighting system design endeavor to produce uniform illumination (measured in lux or footcandles) throughout the office space. Characterizing lighting quality requires the examination of other measures such as patterns of luminance, glare, contrast, veiling reflections, and daylight in the office. The use of indirect luminaires and task lighting often enhance office illumination. It is also important to consider furniture configuration when designing office lighting systems. Advanced lighting controls provide avenues for energy efficiency and a degree of environmental control for the office worker.

The standard office luminaire is the lensed downlight: a 2- by-4-ft fluorescent troffer with prismatic lens and cool white lamps. These luminaires, arranged

row upon row, did an effective job of illuminating the bullpen offices of the 1950s and 1960s. The partitioning of open floor space, however, cast shadows on work surfaces. These inflexible systems are now obsolete for most current office configurations and tasks.

The lensed downlight is counterproductive in the electronic office of the 1990s. Use of VDTs has become the rule rather than the exception. As offices have transformed from paper-based to personal computer (PC)-based, lighting design has not followed. The bright glare of ceiling light is in the direct line of sight as today's office worker looks up into the computer screen instead of down at the desk, as in paper-based offices. The reflection of the ceiling light is visible on the glass VDT. Hours of squinting at glare reflected off the VDT and the constant adjustments of facial muscles causes fatigue, headaches, and backaches from adjusting posture to avoid glare.

It is easy to see why these problems arise by comparing the physical office environment for paper and VDT tasks. The most common visual problem in paper offices is veiling reflections. These are present when light strikes a glossy surface and produces specular reflections that are projected into the viewer's eyes. These reflections act as a veil, reducing the contrast between details-letters and numbers, and the background (the rest of the paper). Lower contrast reduces visibility and requires a greater amount of time to finish the task.

Visual problems in the PC-based office are more complex. The angle of viewing a VDT is nearly horizontal. This places a large area of the ceiling within the file of peripheral vision. Bright spots of light, traditional luminaries, within the field of view can cause disability or discomfort glare. This also applies to unshielded windows within the peripheral field of vision.

Illuminating Engineering Society of North America (IESNA) criteria for VDT lighting has only been in place since 1987. The recommendations rely heavily on criteria from the International Commission of Illumination (CIE). Lighting designers must first assume that VDTs will be in use in every office. Additionally, the location and orientation of VDTs in any given office is unknown—and will likely change in the future. Consequently, the lighting solution must work regardless of where computers are installed in each workspace.

Luminance ratios are important criteria for offices containing VDTs. These affect transient adaptation, disability glare, and discomfort glare. Work surface and office partition reflectance are important, as they often are adjacent to the VDT screen. It is important to limit luminance on ceilings since the nearly horizontal line of sight required when using VDTs places a large area of the ceiling

within the peripheral vision. Luminance ratio criteria are contained in the IESNA's *IES Recommended Practice for Lighting Offices Containing Computer Visual Display Terminals.*

In addition to luminance ratio criteria, limits are also suggested for luminance in the ceiling plane. This is expressed in terms of average luminance at specified cut-off angles, as measured from the vertical. IES criteria recommends that luminaire luminance not exceed:

- 850 candelas per square meter at 55 degrees from vertical;
- 350 candelas per square meter at 65 degrees from vertical; and,
- 175 candelas per square meter at 75 degrees and greater from vertical.

Surface reflectance is an important part of office design as it influences the perception of luminance. Surfaces should be selected to provide the recommended luminance ratios between the average screen and adjacent surfaces.

Modifications to the lighting system itself include use of translucent diffusers, lenses, louver grids or reflectors including parabolic louvers. White diffusers spread light out evenly for a reduced average luminance. Since this image can still be reflected in the VDT, the diffuser option is appropriate for small offices where lighting is located almost directly overhead. Prismatic lenses provide reduced luminance in the 60 to 90 degree range; however, it is not sufficient to prevent an image of the luminaire in the VDT screen. Effectiveness of polarizers is dependent on the degree of polarization, the luminaire-task-eye geometry, and the specularity of the task surface.

"Egg-crate" louvers are made of intersecting straight-sided blades available in a variety of cut-off angles. They generally have enough luminance in the shield zone to cause offensive reflections on the VDT screen.

Parabolic louvers have walls in the form of parabolic reflectors. The cells range in size from 10 by 10 millimeters to almost 300 by 300 millimeters. When manufactured with a specular finish, this louver will have practically no luminance to cause reflected glare on the VDT screens. A limitation of the parabolic as a retrofit is the depth of existing fixtures. Deep-cell louvers must be at least 4-in. deep to provide adequate luminance cut-off.

New illumination systems enable the lighting designer to consider all equipment options in providing a VDT-safe visual environment. Options include using direct lighting, indirect lighting, or a combination of both.

Indirect lighting systems usually require a ceiling of at least 9½ ft. Thus, incorporating lighting into a suspended ceiling hung for the convenience of hiding unsightly HVAC ducts will limit lighting options to recessed or surface mounted luminaries that fit into the 2- by 4-ft grid.

The next generation downlight contains deep cell louvers that prevent light from reflecting off VDTs. It also directs light mostly down, leaving dark shadows on walls. This gives an office the "cave" effect, which can make it an undesirable place to work. Wall washers and indirect lighting can alleviate the cave effect; they work better with modular furniture and office partitions as well as support a more flexible workspace.

Providing lower ambient lighting levels and task lighting as appropriate can also yield energy savings. Uniform illumination levels make employees edgy. The variation in levels of light is more interesting and stimulates workers. Combined task-ambient systems are flexible and allow the frequent office changes inherent to the Army.

Daylight in workplaces is important both psychologically and to minimize energy consumption. Day lighting is considered so important in Germany that office workers must be no farther than 10 m from an outside window. It is also a means to harness renewable energy. Architectural means of harnessing nature's free light include the use of clerestory windows, interior atriums, and light shelves to reflect daylight deep within interior spaces. It is important to provide adequate shading from daylight to prevent disabling glare.

It is critical that individuals preparing new lighting system designs as well as retrofit projects consider all relevant factors. Although energy savings may be the driver for lighting retrofits, designs that fail to consider factors such as surface brightness, glare, and individual controls may defeat the purpose by adversely impacting employee productivity. It is often possible to install effective lighting systems with lighting power densities and capital costs similar to ineffective systems.

3 Lighting Survey Results

Survey Demographics

This study administered a written survey to 107 Continental United States (CONUS) and 47 Outside of Continental United States (OCONUS) energy managers between July and September 1997. Addresses and Points of Contact (POCs) were obtained from Major Command (MACOM) energy managers and the Public Works Telephone Directory. In some cases, energy managers were not available to answer the survey. Surveys were then completed by the individuals with primary responsibility for lighting retrofit projects. The actual survey that was distributed may be found in the Appendix to this report.

Completed surveys were received from 62 CONUS and 19 OCONUS respondents. The following information evaluates the status of existing lighting systems.

Individual Installations

Valid surveys for the building areas listed in Tables 1 and 2 include approximately 46 percent of the 19 returned OCONUS and 27 percent of the 62 returned CONUS. Valid surveys for the building areas listed in Table 3 include approximately 45 percent of the 81 returned.

Table 1. Mean square feet of facilities at installation.

Facilities	OCONUS	CONUS
Barracks	962,551	1,050,262
Administration	717,617	676,795
Maintenance	340,544	385,784
Training	29,569	1,245,508
Housing	3,604,560	1,253,052
Storage	832,942	1,088,421
Hospital	162,799	261,523
Research & Development	2,371	752,856
Community	1,067,593	282,374
Other	123,718	1,914,749

Table 2. Mean number of buildings at installation.

Facilities	OCONUS	CONUS
Barracks	64	26
Administration	94	34
Maintenance	50	23
Training	101	8
Housing	573	531
Storage	120	329
Hospital	6	4
Research & Development	2	98
Community	142	7
Other	186	229

Table 3. Mean percentage of buildings at installation that contain the following energy-efficient lighting technologies.

	T8/elec ballast	CFL lamps	Reflector kits	Occupancy sensors	Dimming systems	HPS lamps	Metal halide	LED exit signs	other
Barracks	30.7%	18.0%	10.3%	1.4%	0.0%	8.3%	1.0%	28.5%	
Admin	33.7%	13.3%	8.1%	5.5%	1.0%	5.7%	1.5%	25.1%	0.9%
Maint	22.1%	10.0%	6.8%	1.0%	0.2%	26.9%	10.7%	12.3%	2.1%
Training	35.6%	12.5%	9.2%	2.1%	2.4%	8.0%	2.8%	21.2%	
Housing	15.6%	10.2%	5.0%	0.0%	0.5%	1.1%	1.0%	6.9%	
Storage	22.3%	7.2%	5.6%	0.5%	0.0%	16.9%	6.4%	21.2%	
Hospital	49.1%	19.8%	12.5%	2.7%	0.3%	8.9%	0.9%	31.2%	
R & D	36.5%	3.9%	5.2%	3.1%	0.4%	4.8%	6.0%	20.9%	
Commun	33.8%	11.4%	9.8%	0.0%	3.2%	2.8%	6.2%	24.4%	

Energy Staff at This Installation

Ninety-six percent of the responses from a pool of 81 returned surveys are valid. Forty-eight percent included a part-time percentage.

- Mean number of full-time staff: 1
- Mean number of part-time staff: 2 @ 28percent.

Individual Experience

Ninety-three percent of the responses from a pool of 81 returned surveys are valid.

- Mean number of years as energy manager: 6
- Mean number of years at this installation: 11

Survey Demographics Summary

The responses for the building areas listed in both Tables 1 and 2 demonstrate that housing facilities at existing CONUS and OCONUS installations occupy the most square footage and account for the largest number of buildings. The data listed in Table 3 indicate that T-8/electronic ballasts are the most used energy-efficient lighting technology in buildings at each installation. Hospitals contain the most T-8/electronic ballasts, CFL lamps, reflector kits, and LED exit signs. Administration buildings contain the most occupancy sensors. Community buildings have the most dimming systems. Finally, maintenance buildings have the most high-pressure sodium (HPS) lamps and metal halides.

The energy staff at Army installations is typically comprised of a small number of employees. Survey results indicated that each installation had approximately one full-time and one part-time employee. Forty-three out of a pool of 81 installations do not have a full-time energy manager. The average number of years that energy managers have spent at each installation is 11, with 6 years as energy manager.

General Survey

The Lighting Retrofit Survey contained 81 data points and was divided into several sections. Respondents were asked their opinion on specific lighting retrofit technologies. They were asked for specific experience in attempting lighting retrofit projects, such as what criteria they felt was important, and what problems were encountered. They were also asked for specific lighting support needs.

The survey was also used to gather information otherwise not available such as the level of staffing in installation energy offices. It also requested specific information on how ECIP and FEMP funds were used in lighting retrofit projects. Respondents were asked for any other comments pertinent to lighting retrofit projects.

Installation Lighting Projects

To understand what characteristics are important when planning and preparing lighting retrofits and new designs, energy staff were asked to rank project criteria from their experience. Eighty-three responses out of a pool of 83 are valid.

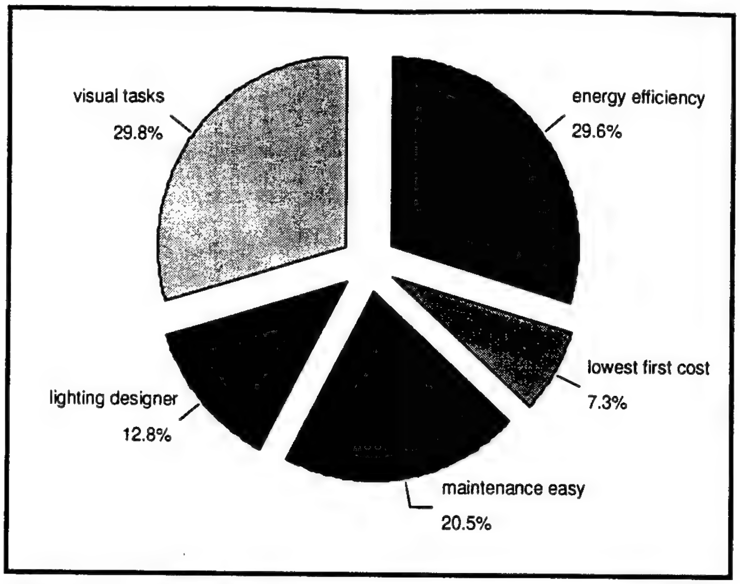

Figure 2. Important characteristics for planning and preparing lighting retrofit and new designs.

Figure 2 shows 100 points distributed among five criteria according to the respondent's opinion of their importance to lighting project planning and design.

General Survey Summary

Supporting visual tasks and energy efficiency were the two major factors in planning lighting. The ability to maintain the new fixtures was mentioned throughout the survey as an important consideration. Energy managers were concerned that they or their staff may not be trained sufficiently to maintain the new technology. Cost of maintenance, and the labor required to replace lamps and to clean and repair fixtures were also mentioned as important factors in retrospect, which may not have been considered in the original design.

Figure 2 shows that the importance of a good lighting designer is ranked lower against other project influences, yet it was mentioned repeatedly throughout the survey by energy managers as a key factor in long-term efficiency. They seemed to be saying, "Do it right the first time."

Lighting Technologies

Respondents were asked to select on a scale of 1 to 5 (where 1=strongly disagree and 5=strongly agree) for the following statements. The resulting percentages represent valid responses from a pool of 83 surveys. Figures 3 to 8 illustrate the mean values for each of the following sections.

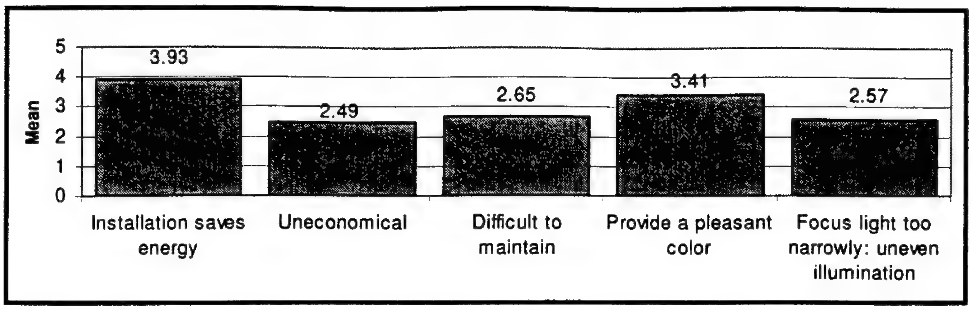

Figure 3. Mean values for responses related to specular reflectors.

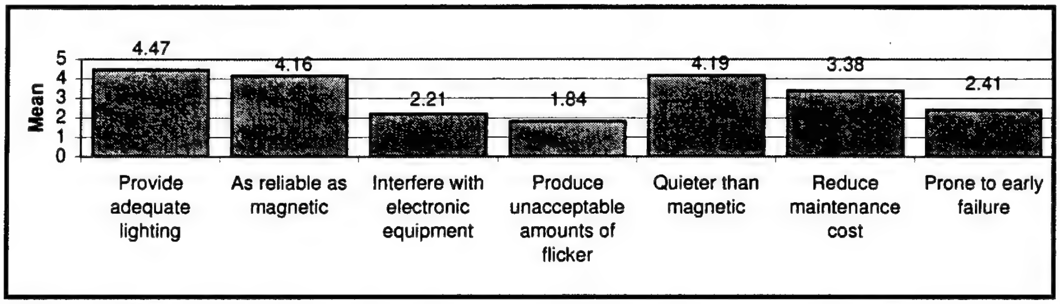

Figure 4. Mean values for responses regarding T-8 lamps and electronic ballasts.

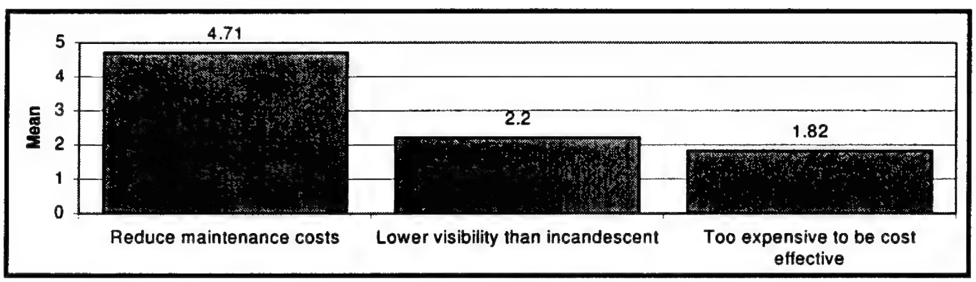

Figure 5. Mean values for responses relating to LED exit signs.

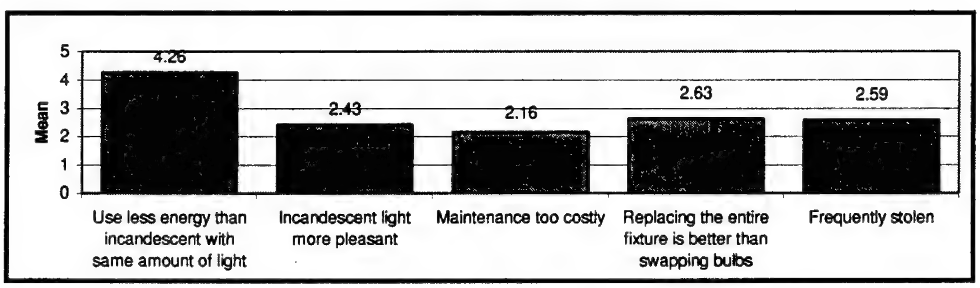

Figure 6. Mean values for responses relating to compact fluorescent lamps.

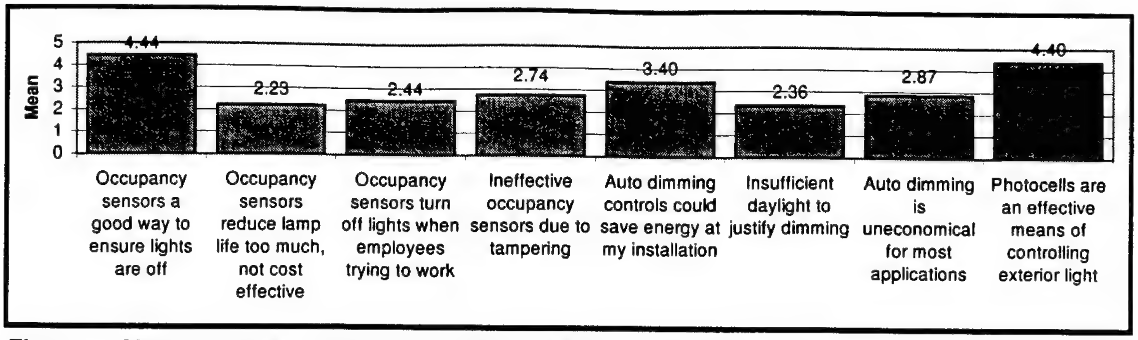

Figure 7. Mean values for responses relating to lighting controls.

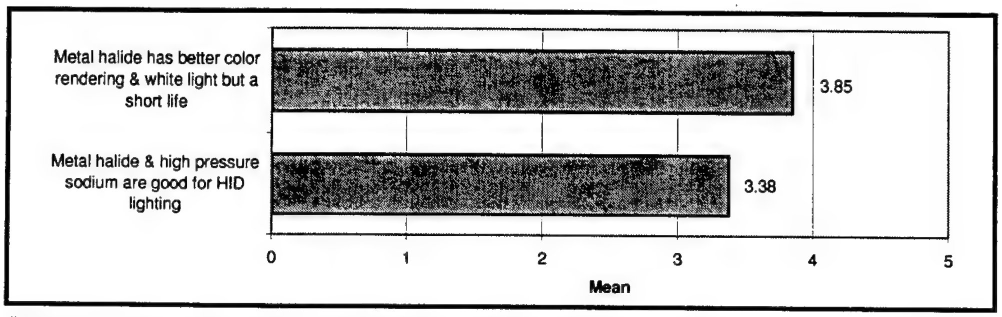

Figure 8. Mean values for responses regarding high intensity discharge lamps.

T-8 Lamps and Electronic Ballasts

Table 4 lists the responses to statements about T-8 lamps and electronic ballasts.

Table 4. Responses to statements about T-8 and electronic ballasts.

Statement	% Response, 1 = Strongly Disagree, 5 = Strongly Agree					No. of valid responses out of a pool of 83
	1	2	3	4	5	
T-8 lamps and electronic ballasts provide adequate lighting	0.0%	2.5%	8.8%	2.5%	61.3%	80
New electronic ballasts as reliable as magnetic	1.3%	6.3%	17.5%	25.0%	50.0%	80
Electronic ballasts interfere with electronic equipment	30.0%	32.5%	26.3%	8.8%	2.5%	80
Electronic ballasts produce unacceptable amounts of flicker	49.4%	29.6%	11.1%	7.4%	2.5%	81
Electronic ballasts are quieter than magnetic	1.3%	2.5%	20.0%	28.8%	47.5%	80
Electronic ballasts reduce maintenance cost	1.3%	7.5%	27.5%	35.0%	28.8%	80
Electronic ballasts prone to early failure	24.4%	32.1%	26.9%	11.5%	5.1%	78

Specular Reflectors

Table 5 lists the responses to statements about specular reflectors.

Table 5. Responses to statements about specular reflectors.

Statement	% Response, 1 = Strongly Disagree, 5 = Strongly Agree					No. valid responses out of a pool of 83
	1	2	3	4	5	
Installing specular reflectors saves energy	3.9%	6.6%	14.5%	42.1%	32.9%	76
Specular reflectors are uneconomical	24.0%	32.0%	25.3%	8.0%	10.7%	75
Specular reflectors are difficult to maintain	18.7%	26.7%	36.0%	8.0%	10.7%	75
Specular reflectors provide a pleasant color	8.0%	10.7%	29.3%	36.0%	16.0%	75
Specular reflectors focus light too narrowly: uneven illumination	20.0%	30.7%	28.0%	14.7%	6.7%	75

LED Exit Signs

Table 6 lists the responses to statements about LED exit signs.

Table 6. Responses to statements about LED exit signs.

Statement	% Response, 1 = Strongly Disagree, 5 = Strongly Agree					No. of valid responses out of a pool of 83
	1	2	3	4	5	
Retrofitting exit signs with LEDs reduces maintenance costs	0.0%	1.3%	3.9%	16.9%	77.9%	77
LED exit signs have lower visibility than incandescent	41.8%	25.3%	13.9%	8.9%	10.1%	79
LED exit signs are too expensive to be cost effective	54.4%	22.8%	13.9%	3.8%	5.1%	79

Compact Fluorescent Lamps (CFLs)

Table 7 lists the responses to statements about compact fluorescent lamps.

Lighting Controls

Table 8 lists the responses to statements about lighting controls. Figure 9 shows the mean values for the responses.

Table 7. Responses to statements about CFLs.

Statement	% Response, 1 = Strongly Disagree, 5 = Strongly Agree					No. of valid responses out of a pool of 83
	1	2	3	4	5	
CFLs provide the same amount of light as incandescents but use less energy	3.8%	5.0%	10.0%	23.8%	57.5%	80
Light from CFLs not as pleasant as from incandescents	29.1%	26.6%	22.8%	15.2%	6.3%	79
CFL maintenance too costly	31.3%	33.8%	26.3%	5.0%	3.8%	80
Replacing the entire luminaire is better than swapping a CFL for an incandescent bulb	27.5%	25.0%	21.3%	10.0%	16.3%	80
CFLs are frequently stolen	26.6%	20.3%	26.6%	20.3%	6.3%	80

Table 8. Responses to statements about lighting controls.

Statement	% Response, 1 = Strongly Disagree, 5 = Strongly Agree					No. of valid responses out of a pool of 83
	1	2	3	4	5	
Occupancy sensors are a good way to ensure lights are off	1.2%	1.2%	7.3%	32.9%	57.3%	82
Occupancy sensors reduce lamp life too much to be cost effective	28.0%	41.5%	19.5%	8.5%	1.2%	82
Occupancy sensors turn lights off while people are trying to work	18.5%	40.7%	23.5%	12.3%	4.9%	81
People tamper with occupancy sensors rendering them ineffective	14.8%	25.9%	39.5%	9.9%	9.9%	81
Auto dimming controls could save energy at my installation	8.8%	21.3%	18.8%	23.8%	27.5%	80
My installation has insufficient available daylight to justify dimming	22.5%	37.5%	26.3%	8.8%	5.0%	80
Auto dimming is uneconomical for most applications	7.7%	32.1%	34.6%	16.7%	9.0%	78
Photocells are an effective means of controlling exterior light	0.0%	7.3%	8.5%	20.7%	63.4%	78

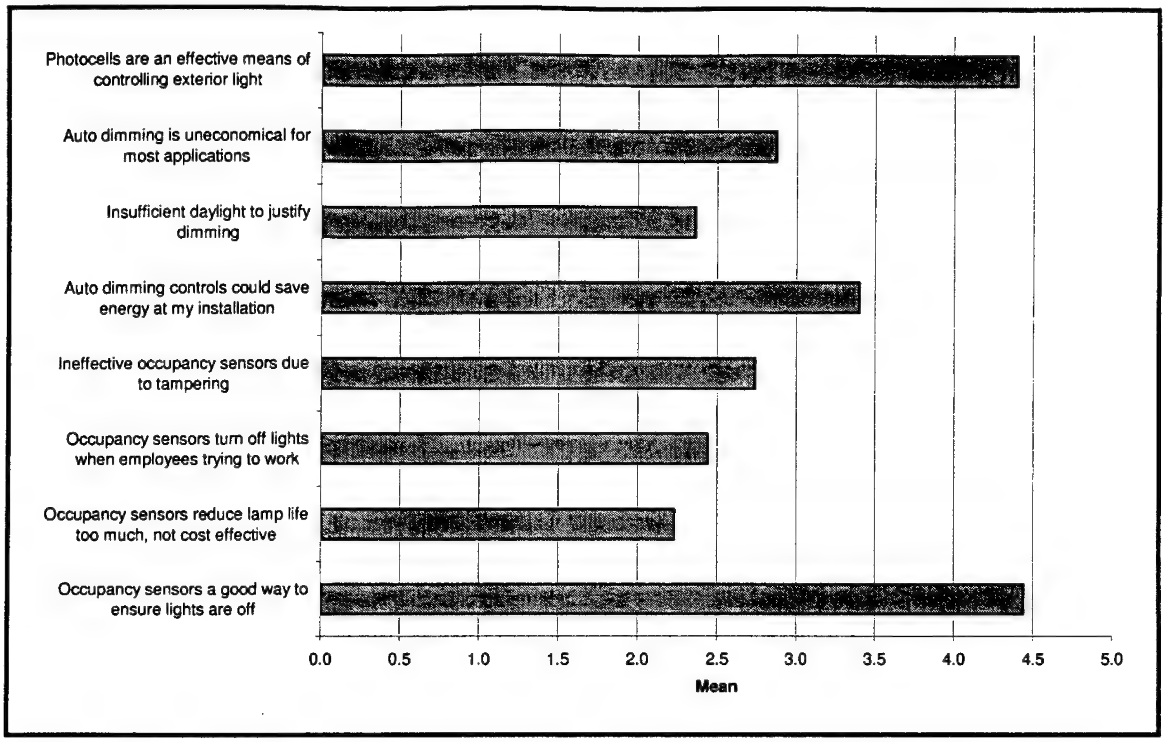

Figure 9. Mean values for responses to questions related to methods that the respondents have used over the last 5 years to carry out their own lighting retrofits.

Table 9. Responses to statements about high intensity discharge lamps.

Statement	% Response, 1 = Strongly Disagree, 5 = Strongly Agree					No. of valid responses out of a pool of 83
	1	2	3	4	5	
Metal halide and high pressure sodium are equally good choices when high intensity discharge lighting is desired	14.1%	16.7%	16.7%	24.4%	28.2%	77
The shorter life of metal halide is offset by its better color rendering and white light	1.3%	6.4%	28.2%	34.6%	29.5%	77

High Intensity Discharge Lamps

Table 9 lists the responses to statements about high intensity discharge lamps.

Barriers

To understand the difficulty, if any, of obtaining high-technology lighting systems, energy staff were asked to identify barriers, based on their experience. Figure 10 identifies barriers to obtaining high-technology lighting systems at the respondent's facility.

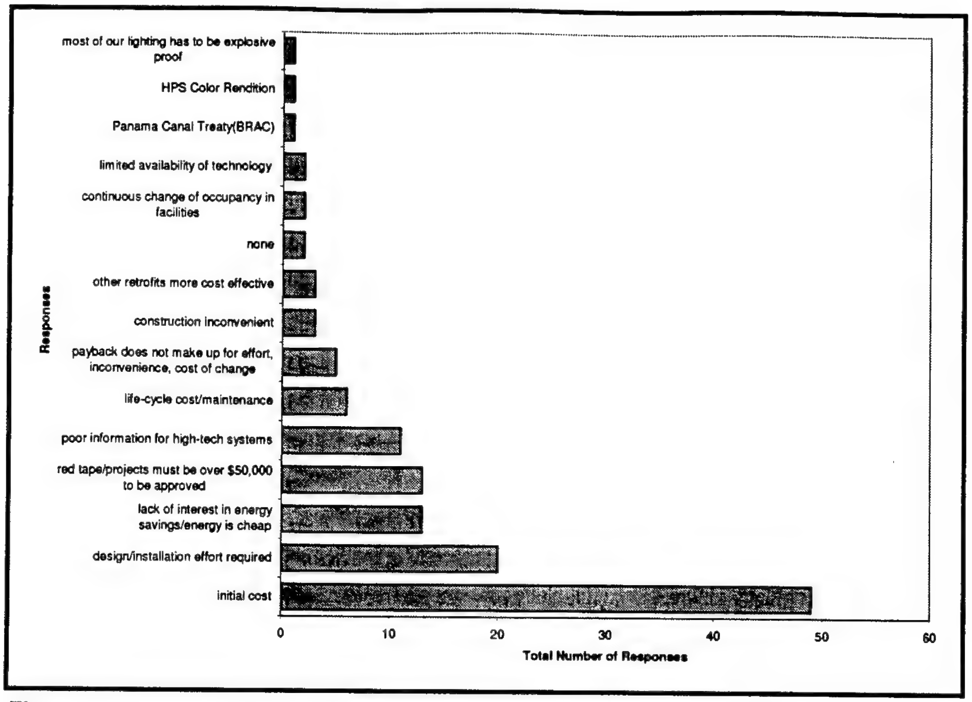

Figure 10. Barriers to obtaining high-technology lighting systems.

Another interesting word of advice survey applicants mentioned was the importance of organization in contracting the lighting project. Contractors and contracts must be carefully chosen. Contractors must be expected to report on work, and to leave the project satisfactorily completed. And there must be communication among the designer, manager, contractor, budget personnel, user, and approval authority.

Approval authorities were mentioned as major obstacles; any designer should know how to work approval authorities. Most importantly, since the decisions of the approval authority affect the entire project from the very beginning, they must be well educated on the lighting technologies being considered, so that they can make informed decisions.

Lighting Technologies Summary

The following are the highest responses that were obtained from the respondents for each of the lighting technology questions. Figure 3 shows that T-8 lamps and electronic ballasts provide adequate lighting, and that compared to units with magnetic ballasts, they are as reliable and quieter. Figure 4 illustrates that specular reflectors save energy while providing a pleasant color. Figure 5 shows that LED exit signs reduce maintenance costs. Figure 6 demonstrates that CFLs provide the same amount of light as incandescents, but use less energy. Figure 7 illustrates that occupancy sensors are a good way to ensure that lights are off

while photocells are an effective means of controlling exterior light. Figure 8 shows that metal halide and high-pressure sodium are desired for high intensity discharge lighting. Overall, the responses to each set of questions in this section were remarkably positive.

Figure 10 shows that the two highest rated barriers to obtaining high-technology lighting systems at facilities are initial cost and the effort required for design and installation. The respondents rated initial cost as the most significant barrier.

Lighting Retrofit Project Experience

The following questions requested that respondents indicate the methods that they have used over the past 5 years to carry out their lighting retrofits.

Respondents were asked to select on a scale of 1 to 5 (where 1=never and 5=always) for the following statements. The resulting percentages represent valid responses from a pool of 83 surveys. Figure 10 shows the mean values of the following responses.

Table 10 lists the methods respondents indicated they have used in the past 10 years to accomplish retrofit projects.

Figure 11 illustrates what respondents would do differently from what they had done in the past if they were to execute a lighting retrofit project tomorrow.

Table 10. Methods respondents have used within the past 5 years to carry out lighting retrofits.

Statement	% Response, 1 = Never, 5 = Always					No. of valid responses out of a pool of 83
	1	2	3	4	5	
In-house design/labor	6.6%	6.6%	47.4%	25.0%	14.5%	76
A-E design	23.6%	12.5%	43.1%	13.9%	6.9%	72
COE Guide Specs	22.5%	19.7%	29.6%	18.3%	9.9%	71
Lighting designer	41.1%	16.4%	23.3%	9.6%	9.6%	73
Existing contract (e.g., JOC)	32.9%	6.8%	38.4%	17.8%	4.1%	73
New contract was awarded	20.3%	8.1%	39.2%	18.9%	13.5%	74
CPW lighting retrofit contract	69.9%	6.8%	15.1%	4.1%	4.1%	73
ESPC or DSM contract	65.3%	8.3%	11.1%	6.9%	8.3%	72

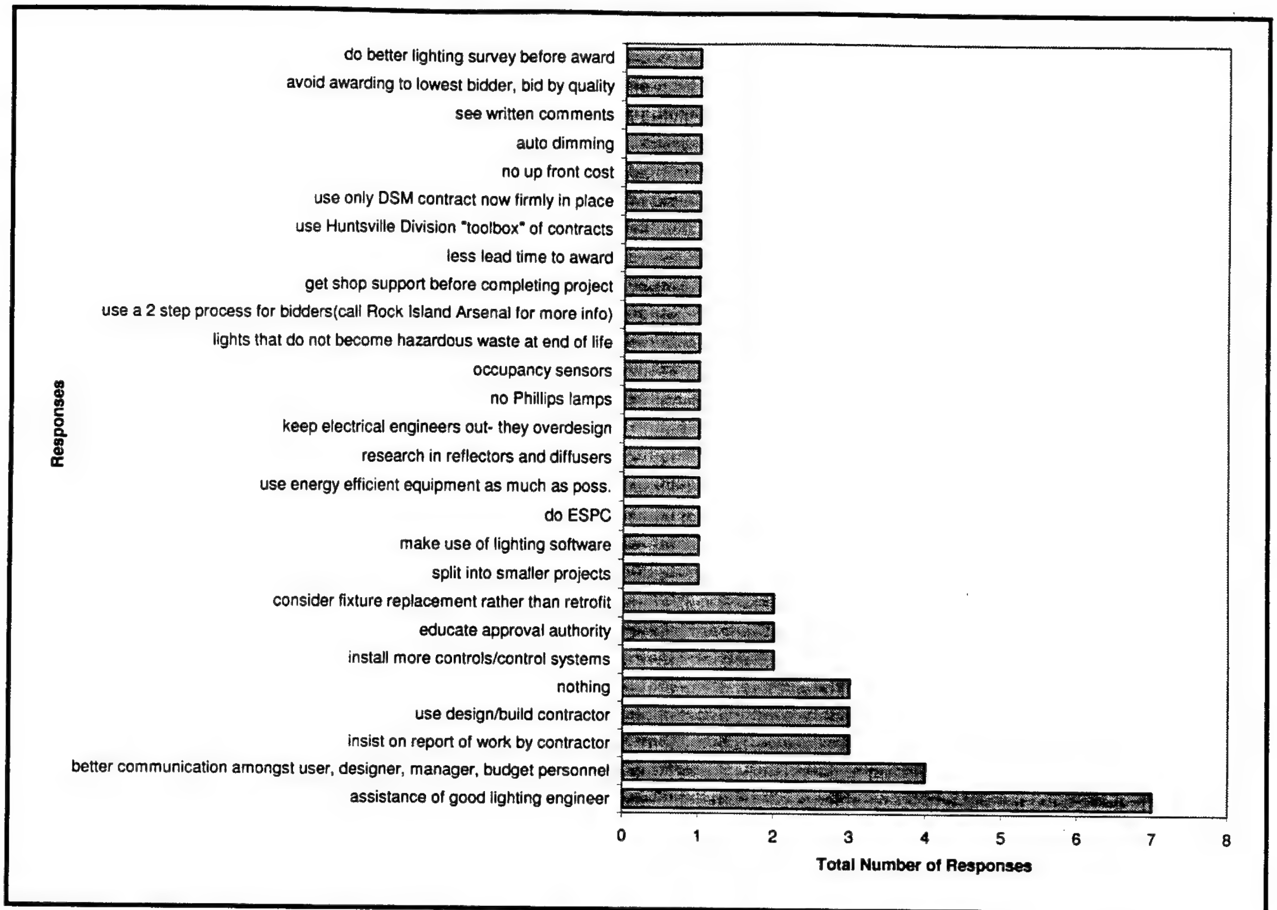

Figure 11. What respondents would do differently than they had in the past if they were to execute a lighting retrofit project tomorrow.

Lighting Retrofit Project Experience Summary

According to Figure 10, the methods employed the most often by respondents over the past 5 years for lighting retrofits are in-house design/labor and newly awarded contracts. The least used are CPW lighting retrofit contracts and ESPC or DSM contracts. Overall the responses for mechanisms employed to execute retrofit projects are steadily "middle of the road."

Responses from Figure 11 indicate that the most important things respondents would do differently for future lighting retrofit projects are obtaining assistance of a good lighting engineer and ensuring better communication among the user, designer, manager, and budget personnel. The assistance of a good lighting engineer received the highest number of responses.

Lighting Support Needs

Responses from 83 valid surveys provide the following values shown in Figure 12. Table 11 lists the respondents evaluation of listed needs "to improve preparation and execution of lighting projects, O&M of lighting systems, and my overall knowledge of energy-efficient lighting technologies."

Lighting Support Needs Summary

The responses illustrated in Figure 12 indicate that more information on available energy-efficient lighting technologies is the most needed improvement in the preparation and execution of lighting projects, O&M of lighting systems, and overall knowledge of energy-efficient lighting technologies. Assistance in doing Post-Occupancy Evaluations is the least important improvement indicated.

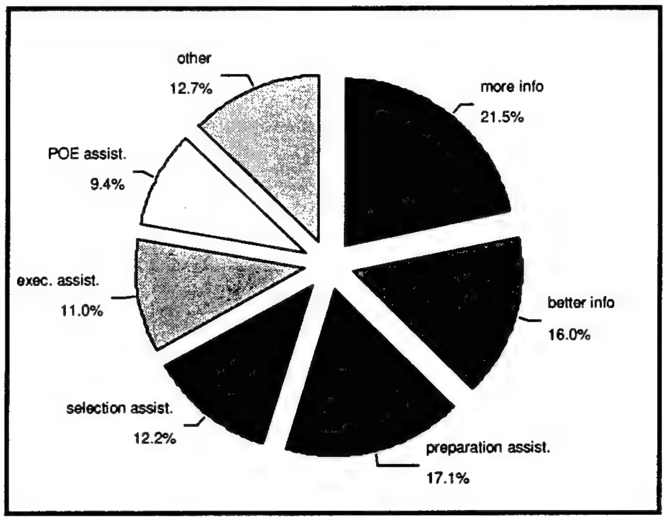

Figure 12. Lighting support needs.

Table 11. Assistance required to improve preparation and execution of lighting retrofits.

Type of Assistance	Mean Responses	%
More information on available energy-efficient lighting technologies	39	21.5%
Assistance in preparing FEMP/ECIP qualifying lighting projects	31	17.1%
Better information on available energy-efficient lighting technologies	29	16.0%
Other	23	12.7%
Assistance in selecting appropriate lighting retrofit technologies	22	12.2%
Assistance in executing lighting retrofit projects	20	11.0%
Assistance in conducting Post-Occupancy Evaluation (POE)	17	9.4%

Problems with Lighting Project Planning or Execution

These questions were intended to identify lighting retrofit problem areas. Respondents were asked to select, on a scale of 1 to 5 (where 1=never and 5=always), their evaluation of the following statements. The resulting percentages represent valid responses from a pool of 83 surveys. Figure 13 illustrates the mean values of the following responses.

Table 12 summarizes responses to the question, "How often are the following problems encountered during planning and execution or after completion of a lighting retrofit project?" Other obstacles encountered by the respondents with planning and executing lighting projects are illustrated in Figure 14.

Responses illustrated in Figure 13 for lighting retrofit problem areas indicate that all listed problem occur at about the same frequency. However, the highest rated problem area is that the installation staff was unaware of the most efficient lighting technologies. Operation and maintenance of the new lighting system is the least problematic.

Figure 14 shows that the most significant obstacles encountered with planning and executing lighting projects are time, money, and personnel. Most of the responses for project information indicate that installations received FEMP funding, most often in 1995. Table 3 reveals that the most funding is used to retrofit T-8 and electronic ballast lighting technologies. Dimming lighting technologies receive the least funding for retrofits.

Figure 15 illustrates that most of the respondents indicate that they do not have time for lighting projects, but the experiences that they have had with them have been good.

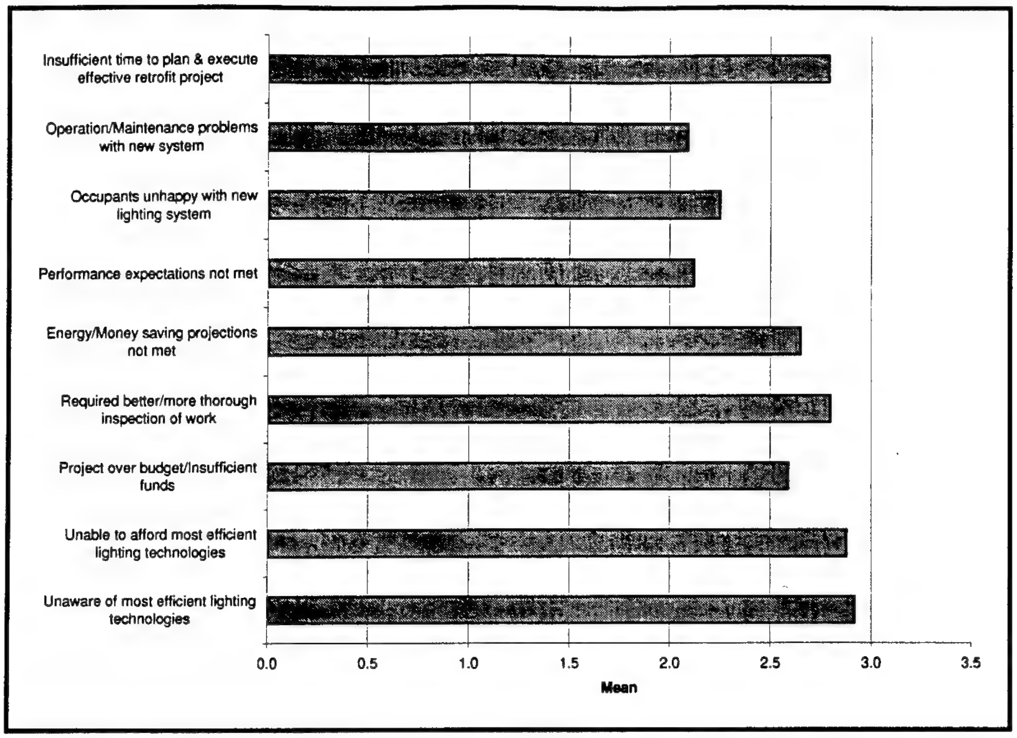

Figure 13. Mean values of responses related to problems with lighting project planning or execution.

Table 12. Problems respondents have encountered during or after a lighting retrofit project.

Statement	% Response, 1 = Never, 5 = Always					No. of valid responses out of a pool of 83
	1	2	3	4	5	
My installation staff was unaware of the most efficient lighting technologies	14.1%	19.2%	32.1%	30.8%	3.8%	78
My installation was unable to afford the most efficient lighting technologies	10.4%	27.3%	32.5%	23.4%	6.5%	78
The project went over budget or we were unable to complete as planned due to insufficient funds	19.5%	29.9%	27.3%	18.2%	5.2%	74
Better/more thorough inspection of retrofit work was required	9.5%	32.4%	29.7%	24.3%	4.1%	73
The project did not meet energy or money saving projections	19.2%	42.5%	20.5%	15.1%	1.4%	75
The installed lighting equipment did not meet performance expectations	18.7%	52.0%	28.0%	1.3%	0.0%	75
The building occupants were unhappy with the new lighting system	14.7%	49.3%	33.3%	2.7%	0.0%	75
There were problems with operation or maintenance of the new lighting system	20.0%	56.0%	18.7%	5.3%	0.0%	75
There was not enough time to plan and execute an effective retrofit project	13.0%	27.3%	33.8%	18.2%	7.8%	77

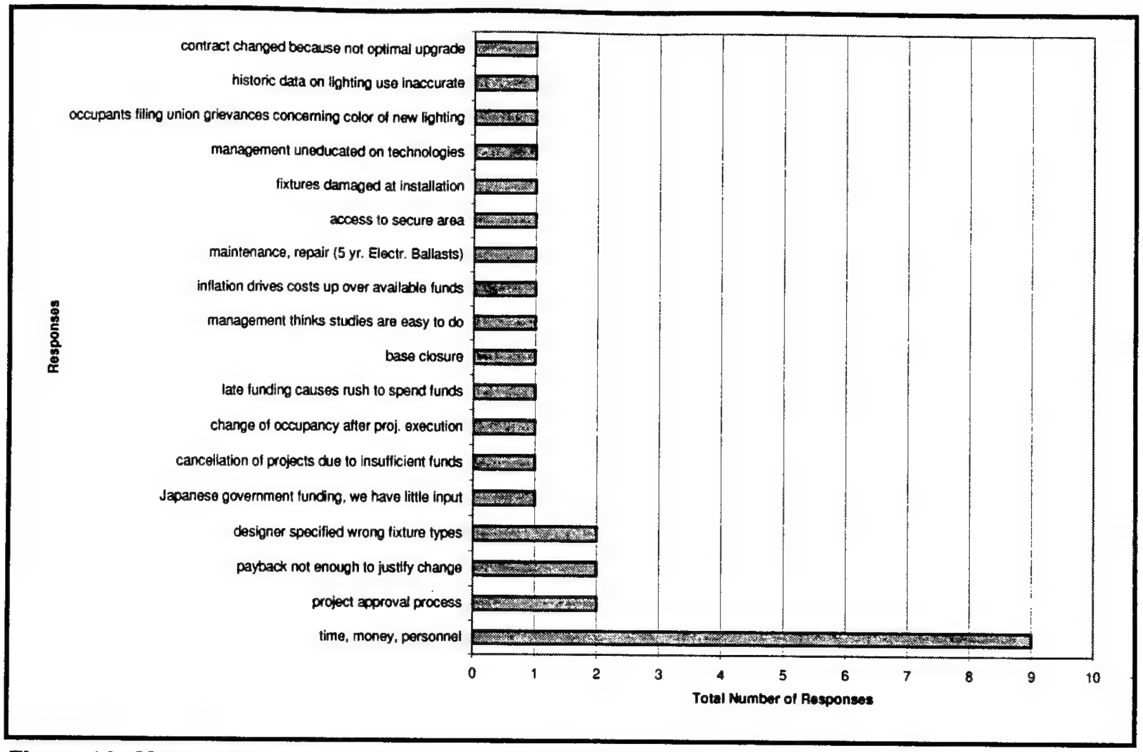

Figure 14. Mean values of responses related to obstacles with planning and executing lighting projects.

Project Information

The Army currently does not have a record of specific retrofits accomplished with FEMP or ECIP funding. The following information will be used to determine penetration rates of energy-efficient lighting technologies and areas where more assistance is needed to infuse lighting technologies. Only information on lighting projects completed in the past 5 years has been included. Approximately 42 out of a pool of 83 surveys are valid for Table 13.

General Lighting Comments

General lighting project experiences and any other comments from respondents are included in Figures 15 and 16. Figure 16 reveals that the most additional comments about lighting in general stated that either facilities had no time for lighting projects or that they were using or pursuing an ESPC for current lighting projects.

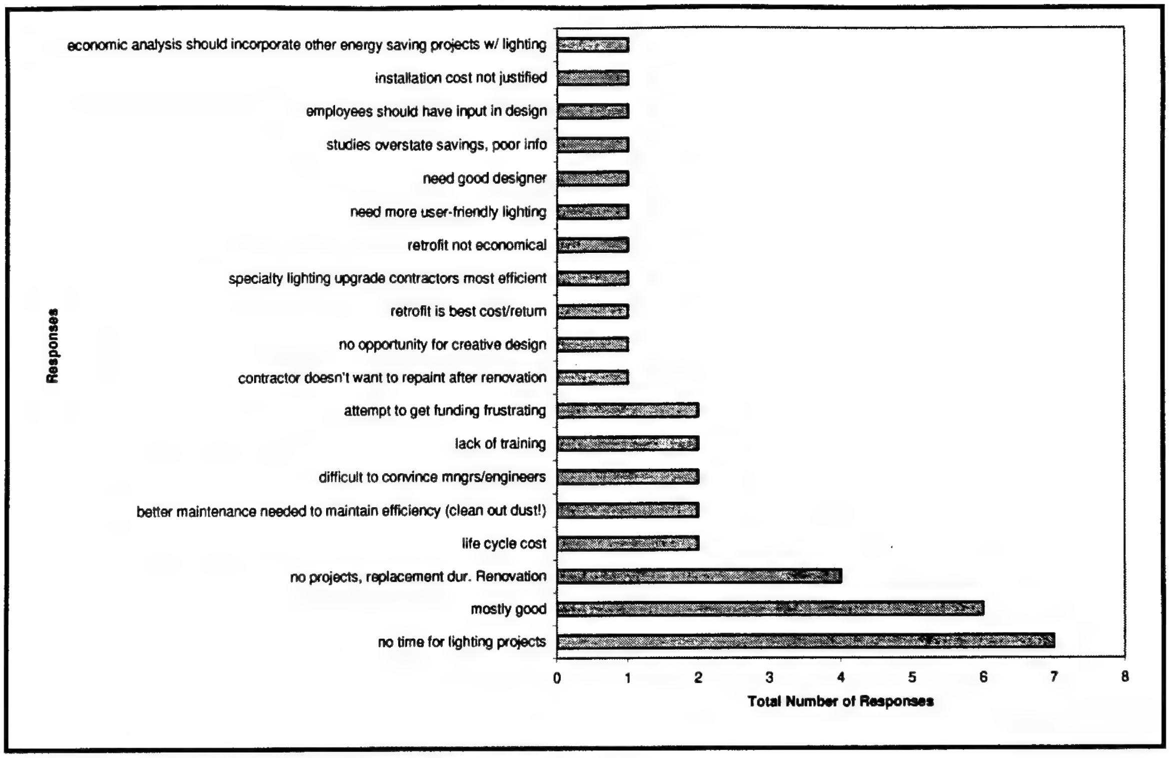

Figure 15. General lighting project experience.

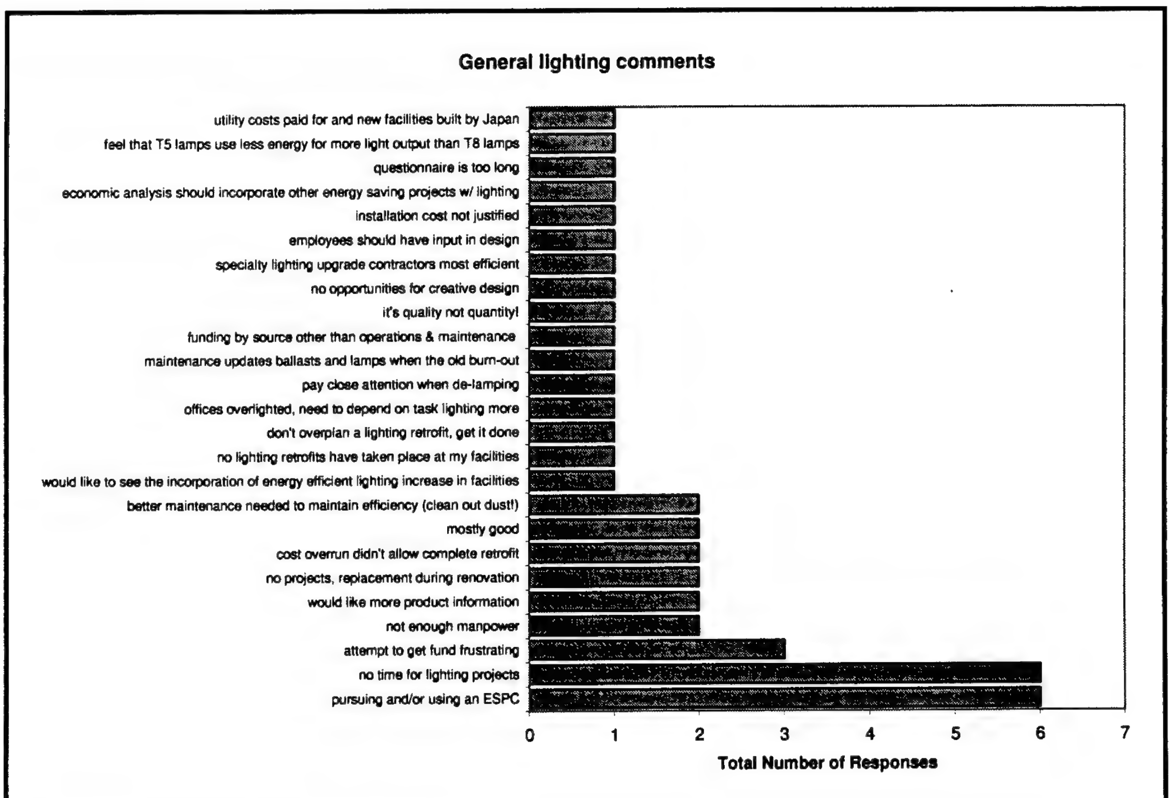

Figure 16. General lighting comments.

4 Conclusions and Recommendations

Conclusions

The lighting retrofit survey highlighted several shortcomings within the Army Energy Program:

1. Foremost is the lack of dedicated funds to accomplish energy conservation projects. No significant energy funding has been available to installations since FY96. Though O&M money can be used for this purpose, it is usually required for provision of basic utilities.
2. Another problem is lack of personnel. The installations represented by the 83 valid surveys had an average of 0.6 full-time energy staff and 1.5 part-time energy staff. This staff often shares duties with the environmental program. Environmental issues are high profile and carry severe consequences if not addressed. Thus, energy conservation takes a back seat on many installations.
3. A last problem is lack of time. Project decisions are often made in short time frames, without the opportunity to gather information, analyze options, and make informed decisions. Thus, beneficial energy related aspects of projects are not achieved.

Since funding levels for energy projects are not anticipated to increase, alternate funding options must be fully explored. It will become increasingly necessary to use experts in the energy field to expedite project decisions and make wise energy choices. A number of Army and National labs provide energy consulting services. Private sector options include Energy Service Companies (ESCOs). Since this survey was conducted, the use of Energy Saving Performance Contracting has increased. Both the Departments of Energy and Defense now offer contracting vehicles that make these mechanisms both easier and more cost-effective to implement. The restructuring of the utility industry also offers opportunities to use outside resources with Utility Energy Service Contracts.

Recommendations

The severe shortage of project funding, energy staff, and time make it imperative that timely, accurate, and easily understood information and tools be available to installation staff involved in the lighting retrofit process. This report gathers much of this information together and references other sources for further information. It is recommended that the technical information, lessons learned, and references provided here be included in future energy staff training venues.

Appendix: Lighting Retrofit Survey

Construction Engineering Research Laboratories
Facilities Technology Lab
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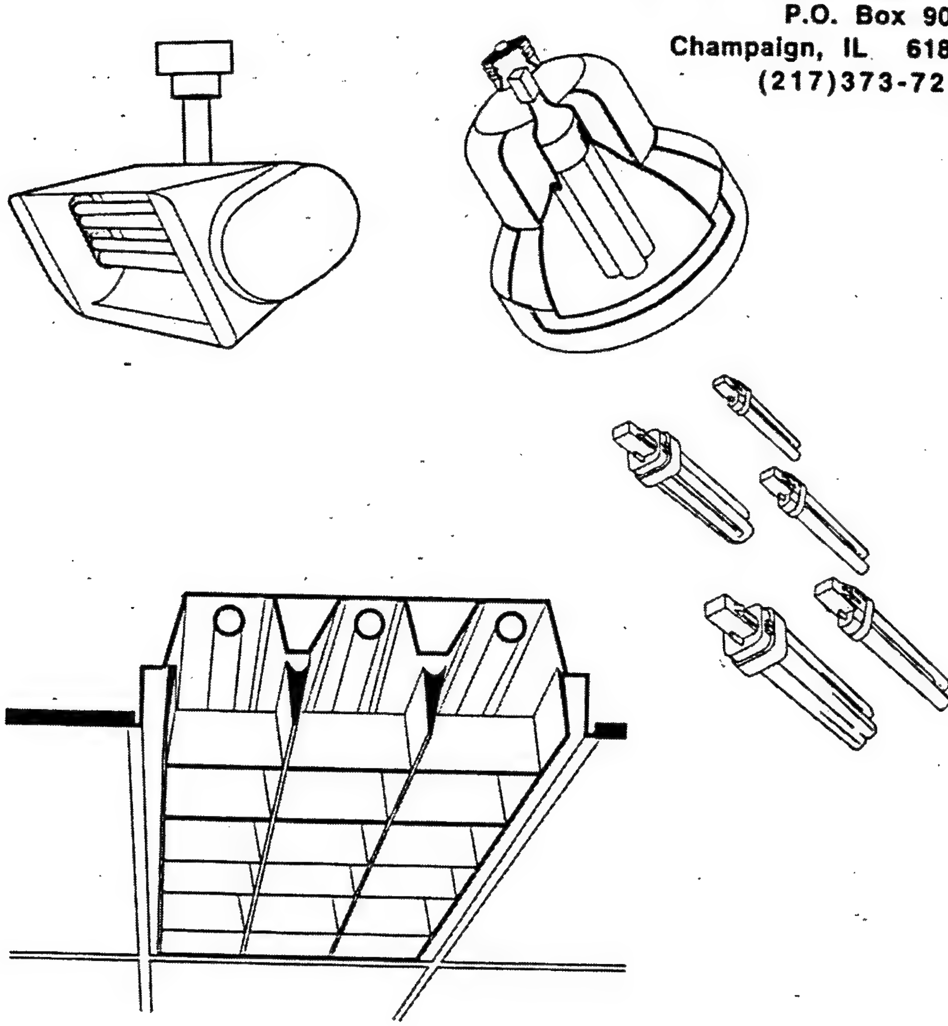

Lighting Retrofit Survey

♦ We are interested in your experiences in planning, executing, and evaluating lighting projects.

♦ Your identity is **confidential** -- your name will <u>never</u> be connected with your answers.

♦ Please return your completed survey in the enclosed stamped envelope.

♦ **EVERY RESPONSE IS IMPORTANT!** Please take a few minutes and tell us about your experiences. This information will help in developing support for installation staff in preparing, executing, and evaluating future lighting retrofit projects and can influence funding of lighting retrofit projects.

This survey is being conducted by Elisabeth Jenicek, Facilities Technology Lab, U.S. Army Construction Engineering Research Laboratories at Champaign, IL.

If you have any questions or concerns, please call Elisabeth at 1-800-872-2375 ext 7238.

The final results and recommendations from this study will be presented to the ACSIM, CPW, CENET, and DoD Energy Managers.

Installation Lighting Projects

We are interested in understanding what characteristics are important when planning and preparing lighting retrofits and new designs.

Listed below are several criteria used for planning new or retrofit lighting sytems.

Please distribute **100 points** amongst the following criteria according to your own opinion of importance to lighting project planning and design.

You may wish to read over all of the criteria before you begin spending your points.
Don't allocate points to any criteria that aren't important to you. Please spend all of your 100 points.

	# points
• Energy efficiency is the most important consideration when selecting lighting equipment	
• Lighting equipment should be selected based on lowest first cost	
• Replacement lighting systems should be easy and economical to maintain	
• It is important to include a lighting designer when planning lighting projects	
• Lighting systems should be designed to support the specific visual tasks of the user	
• Other ______	
Total	100

Please complete this section according to your opinions on the specific lighting technologies.

Lighting Technologies (strongly disagree=1; strongly agree=5)

	Disagree				Agree
T8 lamps and electronic ballasts					
T8 lamps and electronic ballasts provide adequate lighting	1	2	3	4	5
New electronic ballasts are as reliable as magnetic ballasts	1	2	3	4	5
Electronic ballasts interfere with electronic equipment	1	2	3	4	5
Electronic ballasts produce unacceptable amounts of flicker	1	2	3	4	5
Electronic ballasts are quieter than magnetic ballasts	1	2	3	4	5
Electronic ballasts reduce lighting system maintenance costs	1	2	3	4	5
Electronic ballasts are prone to early failure	1	2	3	4	5
Specular Reflectors					
Installing specular reflectors saves energy	1	2	3	4	5
Specular reflectors are uneconomical	1	2	3	4	5
Specular reflectors are difficult to maintain	1	2	3	4	5
Specular reflectors provide a pleasant color of light	1	2	3	4	5
Specular reflectors focus light too narrowly providing uneven illumination	1	2	3	4	5
LED Exit Signs					
Retrofitting exit signs with LEDs reduces maintenance costs	1	2	3	4	5
LED exit signs have lower visibility than incandescent exit signs	1	2	3	4	5
LED exit signs are too expensive to be a cost effective technology	1	2	3	4	5
Compact Fluorescent Lamps					
Compact fluorescent lamps (CFLs) provide the same amount of light as incandescents but use less energy	1	2	3	4	5
The light from CFLs is not as pleasant as that from incandescents	1	2	3	4	5
CFLs are too costly to maintain	1	2	3	4	5
Replacing the entire fixture is better than swapping a CFL for an incandescent bulb	1	2	3	4	5
CFLs are frequently stolen	1	2	3	4	5

Lighting Technologies (cont)

(strongly disagree=1; strongly agree=5)

Lighting Controls

	Disagree				Agree
Occupancy sensors are a good way to ensure lights are off when rooms are not occupied	1	2	3	4	5
Occupancy sensors reduce lamp life too much to provide overall cost savings	1	2	3	4	5
Occupancy sensors turn lights off while people are trying to work	1	2	3	4	5
People tamper with occupancy sensors rendering them ineffective	1	2	3	4	5
Automatic dimming controls could save energy at my installation	1	2	3	4	5
My installation has insuffient available daylight to justify dimming controls	1	2	3	4	5
Automatic dimming controls are uneconomical for most applications	1	2	3	4	5
Photocells are an effective means of controlling exterior lighting	1	2	3	4	5

High Intensity Discharge Lamps

Metal halide and high pressure sodium are equally good choices when high intensity discharge lighting is desired	1	2	3	4	5
The shorter life of metal halide is offset by its better color rendering and white light	1	2	3	4	5

Please identify three barriers to obtaining high-technology lighting systems at your facility

___

___

___

___

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___

___

___

___

Please indicate the methods you have used over the past five years to carry out lighting retrofits.

Lighting Retrofit Project Experience

To execute lighting retrofit projects, the following mechanisms were used:

	Never		Sometimes		Always
• in-house design/labor	1	2	3	4	5
• A-E design	1	2	3	4	5
• CoE guide specs	1	2	3	4	5
• lighting designer	1	2	3	4	5
• existing contract (e.g. JOC)	1	2	3	4	5
• new contract was awarded	1	2	3	4	5
• CPW lighting retrofit contract	1	2	3	4	5
• ESPC or DSM contract	1	2	3	4	5

If you were to execute a lighting retrofit project tomorrow, what would you do differently than you have in the past? Put any other comments here as well.

____
____
____
____
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____
____
____
____

Lighting Support Needs

To improve preparation and execution of lighting projects, O&M of lighting systems, and my overall knowledge of energy-efficient lighting technologies, I need the following:

- ☐ More information on available energy-efficient lighting technologies
- ☐ Better information on available energy-efficient lighting technologies
- ☐ Assistance in preparing FEMP/ECIP qualifying lighting projects
- ☐ Assistance in selecting appropriate lighting retrofit technologies
- ☐ Assistance in executing lighting retrofit projects
- ☐ Assistance in conducting a Post-Occupancy Evaluation (POE)
- ☐ Other ______________________________

These questions are intended to identify lighting retrofit problem areas.

Problems With Lighting Retrofit Project Planning or Execution

How often are the following problems encountered during planning and execution or after completion of a lighting retrofit project?

- My installation staff was unaware of the most efficient lighting technologies

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

- My installation was unable to afford the most efficient lighting technologies

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

- The project went over budget or we were unable to complete as planned due to insufficient funds

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

- Better/more thorough inspection of retrofit work was required

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

- The project did not meet energy or money saving projections

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

- The installed lighting equipment did not meet performance expectations

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

- The building occupants were unhappy with the new lighting system

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

- There were problems with operation or maintenance of the new lighting system

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

- There was not enough time to plan and execute an effective retrofit project

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

Please list any other obstacles you encountered with planning and executing lighting projects:

- ____

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

- ____

_____ Always _____ Usually _____ Sometimes _____ Seldom _____ Never

The following information will be used to assess the status of existing lighting systems. This information will help determine the potential for future lighting retrofit projects.

Demographic Information

My Installation:

- Installation name ____________________
- MACOM ____________________
- CoE district/division providing support ____________________
- Other ____________________

Approximate square feet of facilities at my installation is: ________ TOTAL

barracks_______ admin_______ maintenance______ (_________)_____
training________ housing______ storage_________ (_________)_____
hospital________ R & D_______ community_______ (_________)_____

Approximate number of buildings at my installation is: ________ TOTAL

barracks_______ admin_______ maintenance______ (_________)_____
training________ housing______ storage________ (_________)_____
hospital________ R & D_______ community______ (_________)_____

What is the approximate percentage of buildings in each category that contain the following energy-efficient lighting technologies? e.g. if 50% of the existing incandescent fixtures in admin buildings have been retrofit with CFLs, enter 50% in that space.

	T8/elec ballast	CFL lamps	reflector kits	occupancy sensors	dimming systems	HPS lamps	metal halide	LED exit signs	_____
barracks									
admin									
maint									
training									
housing									
storage									
hospital									
R & D									
commun.									

Energy Staff at This Installation:

Number of staff who work: full time ________
part-time ________ (include % of time)
part-time ________ (include % of time)

My Experience:

Number of years as energy manager ________
Number of years at this installation ________

Project Information

The Army currently does not have a record of specific retrofits accomplished with FEMP or ECIP funding. The information you provide will be used to determine penetration rates of energy-efficient lighting technologies and areas where more assistance is needed to infuse lighting technology.

Please fill in the chart below with information about lighting projects completed in the past five years. The "Project & Funding" column has been filled out where ECIP or FEMP funding was provided for your installation.

What types of lighting projects have been completed on your installation since the Energy Policy Act of 1992? How were they funded? e.g. FEMP, ECIP, DSM/ESPC, OMA, MCA What types of lighting technologies were installed? Please indicate a percentage or dollar value in each column.

Project & Funding	T8/elc blst	CFL lamps	reflectors	occ sensor	dimming	HPS	MH lamps	LED exits
e.g. $250K FEMP FY95-200 KSF; 4 admin bldgs	100% $200K	100% $8K		100% $12K	10% $15K			100% $15K

If you need additional room, please continue on the next sheet

Please describe, in general, your lighting project experiences.

If you have any other comments about lighting in general, please include them here.

Additional Comments

List of Abbreviations and Acronyms

ASAP	Ally Services and Products Directory
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CAD	computer aided drafting
CEISC	U.S. Army Corps of Engineers Installation Support Division
CERL	Construction Energy Research Laboratory
CFL	compact fluorescent lamps
CONUS	Continental United States
COTS	commercial off the shelf
CPW	U.S. Army Center for Public Works
CRI	color rendering index
CU	coefficient of utilization
DISC	Defense Industrial Supply Center
DLA	Defense Logistics Agency
DOD	Department of Defense
DOE	Department of Energy
DPW	Director of Public Works
DSCP	Defense Supply Center Philadelphia
DSM	demand side management

ECIP	Energy Conservation Investment Program
ECO	Energy Conservation Opportunity
EEAP	Energy Engineering Analysis Program
EPA	Environmental Protection Agency
EPACT	U.S. Energy Policy Act of 1992
EPRI	Electric Power Research Institute
ESCO	Energy Service Company
ESPC	Energy Saving Performance Contracting
FEDS	Facility Energy Decision System
FEMP	Federal Energy Management Program
FLEX	Federal Lighting Energy Expert
FRESA	Federal Renewable Energy Screening Assistant
G&I	General and Industrial
HID	high-intensity discharge
HPS	high-pressure sodium
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HVAC	heating, ventilating, and air-conditioning
IESNA	Illuminating Engineering Society of North America
LCCA	life cycle cost analysis
LED	light-emitting diode
LPAD	LightPAD
LSST	Lighting System Screening Tool
LTSM	Lighting Technology Screening Matrix

MACOM	Major Army Command
O&M	operation and maintenance
OCONUS	Outside of Continental United States
PA	Energy Manager Project Assistant
PC	personal computer
PIR	passive infrared
PNNL	Pacific Northwest National Laboratories
REEP	Renewables and Energy Efficient Planning
US	ultrasonic
VDT	Visual Display Terminal
WCO	Water Conservation Opportunities

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14. ABSTRACT

Electrical lighting is a major consumer of energy in Army facilities. Lighting retrofits are often the first energy projects to be completed on Army installations because they require a relatively low investment and yield a quick simple payback. Many energy-efficient, low-cost, commercial off-the-shelf lighting technologies are available. Despite the availability of advanced lighting technologies, successful implementation of lighting retrofits at Army installations is not always realized. This study administered a written survey to Army installation energy managers regarding new lighting technologies and experience with lighting retrofit projects. Analysis of the survey results revealed common problems with lighting retrofits on Army installations. The study also reviewed and presented the types of products, tools, technical support, and processes available to installation staff involved in the lighting retrofit process.

15. SUBJECT TERMS

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